UCRL-JRNL-230717

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Status of the NIF Project

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May 4, 2007

JUNE ISSUE OF THE NEWSLETTER OF THE AMERICAN NUCLEAR SOCIETY-FUSION ENERGY DIVISION

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Status of the NIF Project, **Edward I. Moses, Lawrence Livermore National Laboratory, Livermore, Ca**

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Ground was broken for the National Ignition Facility, a stadium-sized complex, in 1997. When complete, the project will contain a 192-beam, 1.8-megajoule, 500-terawatt laser system adjoining a 10-meter-diameter target chamber with room for nearly 100 experimental diagnostics. NIF's beams will compress and heat small capsules containing a mixture of hydrogen isotopes of deuterium and tritium. These targets will undergo nuclear fusion, producing more energy than the energy in the laser pulse and achieving scientific breakeven. NIF experiments will allow scientists to study physical processes at temperatures approaching 100 million degrees Kelvin and 100 billion times atmospheric pressure—conditions that exist naturally only in the interior of stars and in nuclear weapon detonations.

National Ignition Facility

A cornerstone of the National Nuclear Security Administration's Stockpile Stewardship Program, NIF will help ensure the reliability of the U.S. nuclear weapons stockpile by allowing scientists to validate computer models that predict age-related effects on the stockpile. Access to these regimes will also make possible new areas of basic science and applied physics research. This article summarizes the current status of the NIF project and discuss plans for the first science experiments on NIF.

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NIF's 192 beams are organized in quads, bundles and clusters. Quads are four beams with the same pulse shape. Each NIF bundle—an upper and lower quad—is controlled independently from the others. In July 2001, the NIF project began working on an accelerated set of milestones leading to NIF Early Light (NEL), a campaign to demonstrate NIF's capability to deliver high-quality laser beams to the target chamber in support of early experiments. The first quad was activated in December 2002. On May 30, 2003, NIF produced 10.4 kilojoules of ultraviolet laser light in a single laser beamline, setting a world record for laser performance. By the end of the NEL campaign in October 2004, more than 400 shots had been performed. After NEL NIF began installation of production laser hardware in the rest of the lasers. The first cluster of 48 beams became operational on Dec. 7, 2006, with the demonstrated capability of producing more than a megajoule of infrared laser energy-- establishing NIF's ability to achieve 4.2 megajoules in the infrared when all beams are activated.

NIF is now more than 90% complete, and several significant milestones were recently reached. Seventy-two main laser beamlines are now operating in Laser Bay 2. Each beam has been qualified at 19,000 joules, for an equivalent energy for these 72 beams of 1.4 megajoules (see Figure 1). This is more than 20 times the 1ω energy that any other laser facility has routinely delivered. In addition, 3,731 line replaceable units (LRUs) have been installed. This includes 98% of all LRUs in Laser Bay 2 and 60% in Laser Bay 1. Delivery of laser light into the target bay will begin this summer.

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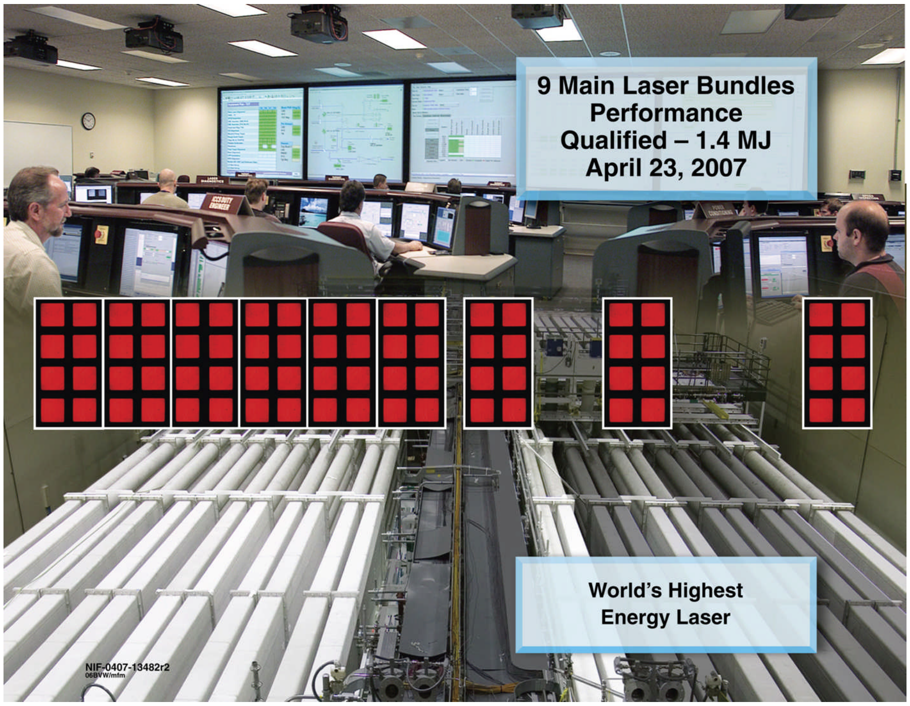

Fig. 1. Seventy-two main laser beamlines are now operating in Laser Bay 2 of the National Ignition Facility. Each beam has been qualified at 19,000 joules, for an equivalent energy for these 72 beams of 1.4 megajoules.

The very complex small optical systems in the laser bays are now nearly 70% complete and progressing quickly. The controls hardware installation is more than 85% complete. Alignment laser light has been brought back to the target chamber center for the first time since the NEL campaign ended in October 2004 – an exciting achievement that foreshadows the return to experiments this coming winter. The facility utility work is moving along rapidly with completion expected by the July 4th holiday. Each of these accomplishments is impressive in its own right. Together, they are truly remarkable. The official project end date is March 31, 2009, a little more than 100 weeks from now, and NIF is on schedule for success.

Big Lasers, Small Targets

As NIF heads toward completion, the enormity of the project has become apparent. Its twin laser bays are each 400 feet long, amplifying beams that are about 16 inches square. The 33-foot-diameter target chamber consists of a million pounds of concrete and aluminum. But NIF's business end – the ignition capsule target – is tiny: just two millimeters in diameter. These capsules are positioned inside a small (one centimeter long) canister known as a hohlraum inside the cavernous NIF target chamber. The 192 laser beams enter the hohlraum from top and bottom, creating X-rays that heat the capsule to temperatures as high as those within the sun. This creates pressures that compress and heat the deuterium-tritium fuel contained inside the capsule, forcing the nuclei inside to undergo fusion while releasing a tremendous burst of energy.

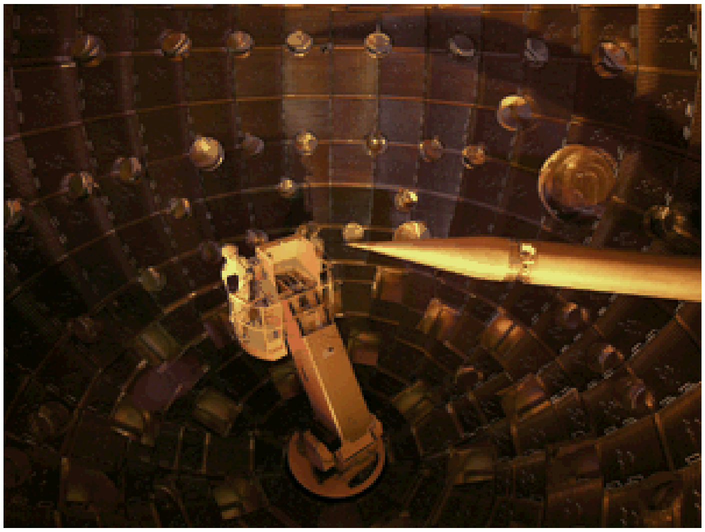

Fig. 2. The NIF target chamber is constructed from 4-inch-thick aluminum and coated with a 16-inch-thick neutron shielding concrete shell. The entire assembly weighs about one million pounds. The target positioner, which holds the target at its tip, is on the right.

The National Ignition Campaign (NIC) integrates the activities required to perform a credible ignition experimental campaign on NIF. NIC is a collaborative effort involving Lawrence Livermore National Laboratory, the University of Rochester Laboratory for Laser Energetics, General Atomics, Los Alamos National Laboratory and Sandia National Laboratories. The NIF and NIC activities are merging at a rapid rate. It is only a little more than a year until 96-beam commissioning activities in the target chamber. This Early Opportunity Shots (EOS) series will establish NIF as a preeminent international high-energy-density (HED) physics facility and set the facility directly on the path to the first ignition experiments in 2010.

NIF produces pulses lasting from 0.2 to 10's of nanoseconds. During recent tests in the Precision Diagnostic Station (PDS) all of NIF performance requirements have been demonstrated on a single-beam basis. These tests demonstrated NIF's capabilities for HED experiments in support of the Department of Energy's Stockpile Stewardship Program and for basic science experiments to explore such topics as the origin and makeup of the planets and the hydrodynamics of supernovae – explosions of massive stars.

The NIF Control System

Another important achievement involved NIF's automated shot controls. The Integrated Computerized Control System (ICCS) was able to fire the entire shot cycle for Cluster 3's 48 beams, including shot setup, data archiving, shot data analysis and post-shot amplifier cooling, in just over three hours. This is the same time previously completed for a single bundle shot cycle and demonstrates scaling of the controls to full NIF capability. The facility has begun around-the-clock operations, Sunday through Friday, in preparation for eventually becoming a 24/7 operating user facility.

Every NIF experimental shot requires the coordination of complex laser equipment. In the process, 60,000 control points of electronic, optical and mechanical devices—such as motorized mirrors and lenses, energy and power sensors, video cameras, laser amplifiers, pulse power and diagnostic instruments—must be monitored and controlled. The precise orchestration of these parts will result in the propagation of 192 separate nanosecond-long bursts of light over a 1-kilometer path length. These 192 beams must arrive within 30 picoseconds of each other at the center of a target chamber 10 meters in diameter, and pointed to within 50 micrometers of their assigned spot on a target measuring less than 1 centimeter long.

Fulfilling NIF's promise requires a large-scale computer control system as sophisticated as any in government service or private industry. Conceived and built by a team of 100 software developers, engineers and quality control experts, the ICCS software, now nearly 85 percent complete, will soon have about 1.6 million lines of code running on more than 850 computers. ICCS, which is operated from a main control room, fires the laser and conducts these experiments automatically. The alignment control system software determines the position of NIF's laser beams on the optics by analyzing sensor video images with a variety of computer-vision algorithms.

Motor control robotics software uses the sensor information to remotely position more than 9,000 stepping motors and other actuators. These devices point the beams through pinholes, center them on mirrors and lenses and focus them onto the target—achieving greater precision and effectively eliminating the need for personnel to adjust the beamlines manually.

Over the next two years, the rest of the laser bundles will be completed and computers and software that were fielded for the initial bundles will be replicated. NIF's independent bundle architecture simplifies the task of controlling the laser because each bundle is prepared for the upcoming shot independently. The bundles are synchronized just before shot time so that even the most complex experiments can be carried out efficiently with a short turnaround time.

Fig. 3. Operators in the NIF Control Room can continuously track data generated by the integrated computer control system on their monitors. The Shot Director's station is on the left.

Lessons from NASA

The design of the NIF central control room is modeled after the National Aeronautics and Space Administration (NASA)'s mission control room in Houston, Texas. Both control rooms have operator stations corresponding to different hardware systems. In NIF's case, each console corresponds to a functional system on the laser. Similar to NASA operators in the Launch Center control room, operators located in the NIF control room continuously track data on their monitors. There are other similarities between executing a NIF shot and launching a Space Shuttle. Launch of a Space Shuttle is controlled by software centered in the Launch Center control room until T minus 31 seconds—or 31 seconds before liftoff; then computers onboard the shuttle take over. Similarly, countdown for a NIF shot includes computer checks of every subsystem, and the control system will automatically stop events from proceeding unless all conditions are satisfactory. At T minus 2 seconds, the ICCS software turns over control to a high-precision integrated timing system designed to trigger thousands of laser modules and diagnostics at exactly the right instant.

The modular control system concept dovetails well with plans for NIF experiments. For example, although achieving ignition will require all 192 beams, many experiments will require fewer laser beams. Each NIF experimental series will require different laser parameters such as wavelength, energy, and pulse duration; different configurations of the laser beam; different laser targets; and different diagnostic instruments. By taking advantage of the facility's experimental flexibility, teams will be able to create an extraordinary range of physical environments, including densities ranging from one-millionth the density of air to 10 times the density of the core of the sun, temperatures ranging from a terrestrial lightning bolt (about 10^4 K) to the core of a carbon-burning star (10^9 K) and pressures from 1 to 100 terapascals (1 gigabar). Researchers will study phenomena at timescales ranging from fractions of a microsecond (10^{-6} seconds) to picoseconds (10^{-12} seconds).

Exploring Frontier Science

In addition to supporting of the Department of Energy's Stockpile Stewardship Program, NIF will provide researchers from universities and Department of Energy (DOE) national laboratories unparalleled opportunities to explore "frontier" basic science in astrophysics, planetary physics, hydrodynamics, nonlinear optical physics, materials science, and inertial confinement fusion. About 15 percent of NIF shots will be devoted to science experiments in these fields. The first science studies will focus on re-creating in the laboratory the properties of celestial objects under scaled conditions. With its 192 beams together generating up to 1.8 megajoules of energy, the giant laser will allow scientists to explore some of the most extreme conditions in the universe such as the hot, dense plasmas found in stars.

NIF experiments will help scientists understand the mechanisms driving new stars, supernovae, black holes, and the interiors of giant planets. The physical processes of stars have long been of interest to Livermore researchers because the prime stellar energy mechanism, thermonuclear fusion, is central to the Laboratory's national security mission. For decades, Livermore researchers have advanced astrophysics by applying their expertise in HED physics and computer modeling of the nuclear processes that take place in these regimes.

Once NIF attains ignition (a burst of fusion reactions in which more energy is liberated than is input), a flux of 10^{32} to 10^{33} neutrons per square centimeter per second will be generated, a rate that may allow excited-state nuclear reactions to occur. This neutron flux will also enable scientists to extend their understanding of the nucleosynthesis of heavy elements, those nuclei more massive than iron. Scaled NIF experiments will permit studies of the entire life cycle of a star, from its birth in a cold, dense molecular cloud through its subsequent stages of evolution to an explosive death such as a supernova.

Once formed, stars are heated by nuclear fusion in the interior and cooled by radiation emissions at their surface, called the photosphere. Opacities of each layer control the rate at which heat moves from the core to the surface. In this way, opacity plays a major role in determining the evolution, luminosity and instabilities of stars. Experiments will mimic stellar plasma to obtain information on the opacities of key elements such as iron and determine how opacity changes with plasma density and temperature throughout a star's lifetime. Experimenters plan to simultaneously measure the radiation transmission, temperature and density of a material sample.

NIF managers are devising a detailed plan for engaging external participation and collaboration. The goal is to turn NIF into a premier international center for experimental science, much like the Advanced Photon Source at Argonne National Laboratory or the

Stanford Linear Accelerator Center. The plan is for NIF to be a user facility by 2012 in areas of HED and basic science and uses of ignition.

Fig. 4. The National Ignition Facility, the world's largest laser, has 192 laser beams, covers the area of three football fields, and stands 85 feet tall. Currently under construction at Lawrence Livermore National Laboratory in California, it will be completed in 2009.

* This work was performed under the auspices of the U.S. Department of Energy National Nuclear Security Administration by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.